# COMPARISON OF VICKERS HARDNESS MEASUREMENT IN HIGH HARDNESS RANGE

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# COMPARISON OF VICKERS HARDNESS MEASUREMENT IN HIGH HARDNESS RANGE

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***Abstract*** − The paper describes comparison of Vickers hardness measurement in the high hardness range. The measurements were performed on the block made of WC-Co hardmetal on the reference Vickers hardness machine. The software package for the indentation analysis was developed. In order to confirm reliability of the results the hardness measurements were performed on the primary Vickers microhardness machine. On the basis of comparison was concluded that measured Vickers hardness fit well.

*Keywords*: Vickers hardness, indentation analysis, hardness standard, comparison, high hardness range

## 1. INTRODUCTION

Hardness is a relative measuring quantity that has no fundamental unit in the SI system. It is determined on the basis of measurement which consists of two basic steps. Primary measurement is a measurement of length; the diagonal/diameter of indentation or indentation depth is measured. The second step is a calculation of hardness value according to a mathematical expression for a particular measurement method based on the previously measured length. Accordingly, the majority of errors in hardness measurements arise from the indentation diagonal measurement [1, 2].

Hardness measurement in high hardness range poses many difficulties and problems. The most common ones are the cracking and chipping of a material on the corners of indentation as a consequence of applied load [3-4]. For that reason hardness is measured with small values of applied load. For the small values of applied load the diagonal of Vickers indentation is very small; for hardness values of approximately 2000 HV1 the diagonal of Vickers indentation is approximately 31 microns [5]. In cases of such small dimensions, the subjectivity of measurements and the limitation of resolution and magnification can significantly affect measured hardness values. Adjustment of proper illumination is very important in determining tip location. The difference in readings of only one micron causes a change in Vickers hardness of approximately 100 -150 HV1 for hardness value approximately 2000 HV1. Small cracks on the corners of indentation can significantly influence the proper tip location and can increase the length of the diagonals. For all these reasons the quality and metrological characteristics of the optical measuring device influence the measured hardness value.

## 2. MATERIALS AND METHODS

Hardness measurements were performed on the Vickers hardness block made of WC-Co hardmetal with hardness value of approximately 2000 HV1. For that purpose, the test surface of the Vickers hardness block was divided into divisions; two circumferential and four radial divisions (Fig. 1). The force applied was 9.807 N, which corresponds to HV1 measuring method. For reliable hardness measurement, five indentations were placed and measured in each section. A total of 40 indentations were placed. Hardness measurements were carried out according to EN ISO 6507-1:2005.

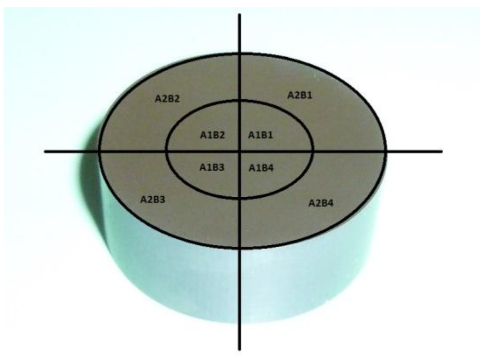



**Fig. 1 – Sections of Vickers hardness blocks**

In each section the mean hardness value was calculated according to equation:

$$\overline{X_j} = \frac{\sum_{i=1}^{n} X_{ij}}{n};\ j = 1,2.,3.k$$

Also, the reference hardness value of the block was calculated. Reference hardness value represents the arithmetic mean of the measured hardness values of all eight sections and is determined by the mathematical expression:

$$\overline{X} = \frac{\sum_{i=1}^{n_j}\sum_{j=1}^{k} X_{ij}}{n} = \overline{H} = \frac{1}{n}\sum_{i=1}^{n} H_i$$

where:
n - number of sections, indentations
$H_i$ - mean hardness of section, hardness of each indentation

Hardness measurements were performed on the reference Vickers hardness machine installed in the Laboratory for Testing Mechanical Properties LIMS at the Faculty of Mechanical Engineering and Naval Architecture (Fig. 2).


**Fig. 2 - Reference Vickers hardness machine**

The load was applied by weights of corresponding mass over the lever system. The weights of the load measuring system were developed based on gravimetric measurements (acceleration of gravity) at the location of installation. Integral part of the reference Vickers hardness machine is optical measuring system I/G-258 which consists of optical microscope. Calibration measurement capability of reference Vickers hardness machine amounts 2%HV for all measuring methods including HV1. The magnification of the optical measuring system I/G-258 significantly affects measured hardness values in the high hardness range (in case of very small indentations). In order to achieve more accurate and precise measurements of indentations, the diagonals were analysed on an opto-electric system installed in the National Laboratory for Length, LPMD at the Faculty of Mechanical Engineering and Naval Architecture (Fig. 3). The CCD-LPMD opto-electric system used for the calibration of precision measuring scales consists of a uniaxial control system, an optical microscope with a built-in high quality CCD camera with an increase of up to 200x and a laser interferometer for the measurement of displacement achieved. The camera is connected to the computer software package Olympus DP-BSW manager, which downloads and processes images from the camera. The camera contains a CCD chip with a 12.5 million pixel progressive scan system.

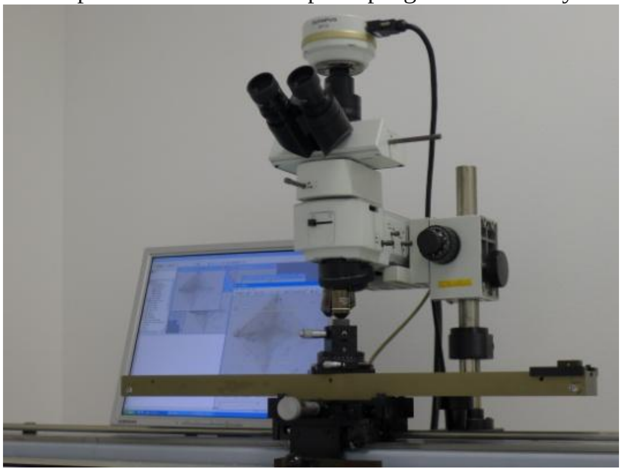
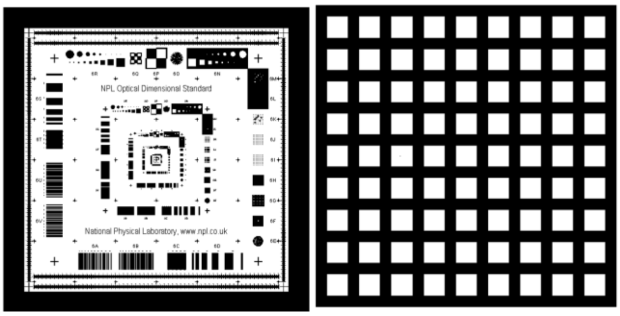


**Fig. 3 - Opto-electric system CCD-LPMD**

For the purpose of indentation analysis the software package was developed where the length of the indentation diagonal was measured in pixels. The length of a single pixel, for a given magnification, was calibrated with the use of 2D NPL standard and the laser interferometer. Calibration was performed by measuring the dimensions of certain features (line thickness, width and spacing square mesh) at 2D NPL standard using the laser interferometer. 2D NPL standard with certain features used for calibration is presented in Fig. 4.




**a) b)**

**Fig. 4 - 2D NPL standard**
**a) 2D NPL standard**
**b) certain features on 2D NPL standard**

The number of pixels in the feature was determined on the captured images of 2D NPL standard using developed software. The same measurement procedure (manual selection of the start and end of features) was later used to measure the diagonals of Vickers indentation. Measurement of dimensions of certain features as well as measurement of the number of pixels to capture these features was carried out 10 times on the basis which the mean values are calculated. The amount of the one-pixel for a certain magnification was expressed as (the length of measured features) / (number of pixels). Expanded measurement uncertainty of calibration with coverage factor $k$=2 and level of confidence $P$=95% was calculated and amounts:

$$U_L = (0{,}2 + 0{,}3L)\text{, µm}$$

where:
L - length of the diagonal, m

Knowing the measurement uncertainty of each component it was estimated that the measurement capability of the entire system (reference Vickers hardness machine and opto electric system CCD-LPMD with newly developed software) amounts 2%.

In order to confirm reliability of the hardness values determined on newly developed software for indentation analysis the hardness measurements were performed on the primary micro-hardness machine producer: Shimadzu Corporation Kyoto, Japan; type: HMV-2000, installed in Physikalische-Technische Bundesanstalt, PTB, Germany (Fig. 5).


**Fig. 5 - Primary micro-hardness machine**

The machine realizes the force directly using weights. The hardness machine has a built-in high-quality microscope with a CCD camera Olympus DP70, a CCD chip, which has a 12.5 million pixel progressive scan system. For the purpose of indentation diagonal measurement, the camera was connected to a computer that allows downloading and processing images from the camera. Measurement capability of primary micro-hardness machine for measuring method HV1 amounts:

$$8 \times 10^{-6} HV^{2} + 0{,}0145 HV + 0{,}58$$

## 3. RESULTS

The results and comparison of Vickers hardness values measured by reference Vickers hardness machine and primary micro-hardness machine are presented in Table 1. The mean hardness values in each section were calculated. Graphical presentation of mean hardness values for each block section and reference hardness values is presented in Fig. 6.

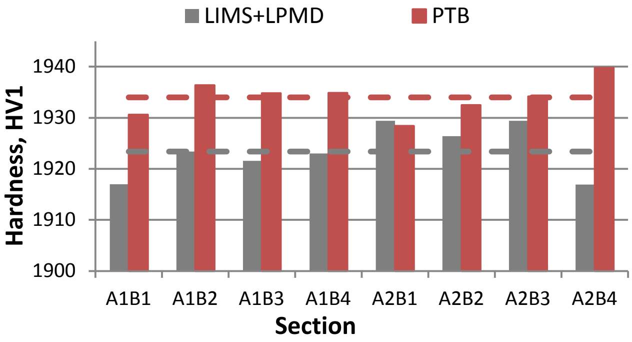



**Fig. 6 - Comparison of Vickers hardness measurement**

Lower mean hardness values for all sections were measured on the reference Vickers hardness machine and opto-electric system CCD-LPMD. As can be seen from Table 1 the reference Vickers hardness value amounts 1923.4 HV1 while the reference Vickers hardness value measured on the primary micro-hardness standard amounts 1934.0 HV1. Reference values of measured hardness differ for 10 HV1 what is within the uncertainty of hardness machines on which the measurements were performed and within the uncertainty of reference block calibration. The largest deviation of the mean value was observed in the section A2B4 and it amounts 22.9 HV1, while the smallest deviation of the mean value is recorded for section A2B1 and amounts only 1HV1. Here is important to emphasise that the measurement uncertainty of LIMS+LPMD is estimated on the basis of measurement capability calculations of separate systems. After confirmation of the reliability of measured Vickers hardness and improvements of the system the measurement capability for the high hardness range with more reference hardness block would be calculated.

During measurements on the opto-electric system CCD-LPMD it was noted that the lens, magnification and illumination influence on the proper tip location and consequently on the reliability of the diagonal length measurement. For that reason improvements of the system will be the subject of future research in order to minimize influences on the Vickers hardness measurement.

**Table 1 - Results and comparison of measured Vickers hardness**

| Section | LABORATORY | | | | | |
|---|---|---|---|---|---|---|
| | LIMS+LPMD | | | PTB | | |
| | Mean hardness value, HV1 | Reference hardness value, HV1 | Estimated measurement uncertainty (k=2), HV1 | Mean hardness value, HV1 | Reference hardness value, HV1 | Measurement uncertainty (k=2), HV1 |
| **A1B1** | 1917,0 | **1923,4** | **39,0** | 1930,6 | **1934,0** | **58,3** |
| **A1B2** | 1923,4 | | | 1936,4 | | |
| **A1B3** | 1921,6 | | | 1934,8 | | |
| **A1B4** | 1923,0 | | | 1934,9 | | |
| **A2B1** | 1929,4 | | | 1928,4 | | |
| **A2B2** | 1926,4 | | | 1932,5 | | |
| **A2B3** | 1929,4 | | | 1934,2 | | |
| **A2B4** | 1916,9 | | | 1939,8 | | |

## 4. CONCLUSION

On the basis of comparison was concluded that measured hardness fit well. Reliability of Vickers hardness values measured on newly developed software package for the indentation analysis was confirmed. Reference values of measured hardness are within the uncertainty of the hardness machines on which the measurements were performed and within the uncertainty of reference block calibration. This opens the possibility for LIMS and LPMD to participate in an international comparison for the high hardness range and the confirmation of the measurement capability. Detailed measurement uncertainty budget for the entire system (reference Vickers hardness machine and opto electric system CCD-LPMD with newly developed software) is planned in future work. Also, the improvements of the system will be the subject of future research in order to minimize influences on the Vickers hardness measurement.

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